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Light quark distributions in the proton sea

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We use the meson cloud model to calculate $\bar{d}(x) - \bar{u}(x)$ and $\bar{d}(x)/\bar{u}(x)$ in the proton. We show that a modification of the symmetric, perturbative part of the light quark sea provides better agreement with the ratio $\bar{d}(x)/\bar{u}(x)$.

1. Introduction

Flavor asymmetry in the light quark sea of the proton has been well-established by experiment [1–4]. The violation of the Gottfried sum rule found by NMC [1] indicated that $D \equiv \int_0^1 dx\ (\bar{d}(x) - \bar{u}(x)) = 0.148 \pm 0.039$. In Drell-Yan experiments, $\bar{d}/\bar{u}$ was determined to be greater than 2 at $x = .18$ by NA51 [2], and the x-dependence of this ratio has recently been measured by E866 [3] in the region $0.02 \leq x \leq 0.345$. From their data and global parton distributions [5] E866 also determined the difference $\bar{d}(x) - \bar{u}(x)$ and $D = 0.100 \pm 0.018$. Flavor asymmetry consistent with these results has also been seen in the measurement of $\bar{d}(x) - \bar{u}(x)$ by HERMES [4].

It was first suggested by Thomas [6], and later by Henley and Miller [7] that a natural explanation for this asymmetry is the meson cloud of the proton. The net positive charge of the cloud leads to an excess of $\bar{d}$ over $\bar{u}$. Other causes for the asymmetry have been invoked, such as antisymmetrization [8,9], but these have been insufficient to describe the data. For reviews, see Refs. [10,11].

We wish to emphasize that the E866 measurements provide a critical test of our understanding of the flavor-symmetric (FS) contributions to the light quark sea, as well as the flavor-asymmetric (FA) contributions. Meson cloud models [9,12–15] provide a reasonably good description of the $\bar{d}(x)-\bar{u}(x)$ asymmetry, which depends on FA contributions alone, but fail to explain the broad maximum in the ratio $\bar{d}(x)/\bar{u}(x)$ at $x \approx 0.18$ and its return to unity, or even lower values, at larger x. FS terms also contribute to this ratio

$$\frac{\bar{d}(x)}{\bar{u}(x)} = \frac{\bar{d}(x) - \bar{u}(x)}{\bar{u}(x)} + 1, \tag{1}$$

[*]Contributions to the work described in this talk have been made by students Thomas Falter (University of Giessen) and Adam Graunke (Seattle University).

and it is clear that $\bar{u}(x)$ falls too rapidly with x in these models. We have proposed [16] that agreement with data can be improved by using harder distributions for the perturbative contributions to $\bar{u}(x)$, motivated by their origin in gluon splitting.

2. Pion cloud model

To illustrate this argument we use a pion cloud model. Other states should be included in a full calculation, but e.g. the ρ meson increases $\bar{d}(x)-\bar{u}(x)$, whereas the intermediate Δ decreases it, so these effects tend to cancel. The wave function of the proton is written in terms of a Fock state expansion

$$\mid p\rangle = \sqrt{Z}\mid p\rangle_{\rm bare} + \sum_{MB}\int dy\, d^2\vec{k}_\perp\, \phi_{BM}(y,k_\perp^2)\mid B(y,\vec{k}_\perp)M(1-y,-\vec{k}_\perp)\rangle\ , \qquad (2)$$

with $BM = p\pi^0, n\pi^+$. The factor $\sqrt{Z}$ is a wavefunction renormalization constant and $\phi_{BM}(y,k_\perp^2)$ is the probability amplitude for finding a physical nucleon in a state consisting of a baryon B with longitudinal momentum fraction y, transverse momentum $\vec{k}_\perp$, and a meson M of momentum fraction $(1-y)$, transverse momentum $-\vec{k}_\perp$. The quark distribution functions $q(x)$ in the proton are given by

$$q(x) = q^{\rm bare}(x) + \delta q(x)\ , \qquad (3)$$

with

$$\delta q(x) = \sum_{MB}\left(\int_x^1 f_{MB}(y) q_M(\frac{x}{y})\frac{dy}{y}\ + \int_x^1 f_{BM}(y) q_B(\frac{x}{y})\frac{dy}{y}\right), \qquad (4)$$

$$f_{BM}(y) = \int_0^\infty \mid \phi_{BM}(y,k_\perp^2)\mid^2\ \ d^2k_\perp\ , \qquad (5)$$

and

$$f_{MB}(y) = f_{BM}(1-y)\ . \qquad (6)$$

The splitting function $f_{n\pi^+}(y) = 2f_{p\pi^0}(y)$, with [10,17]

$$f_{p\pi^0}(y) = \frac{g^2}{16\pi^2}\frac{1}{y^2(1-y)}\int_0^\infty dk_\perp^2 |G_\pi(y,k_\perp^2)|^2 \frac{m_N^2(1-y)^2+k_\perp^2}{[m_N^2 - M_{N\pi}^2(y,k_\perp^2)]^2}, \qquad (7)$$

in which $M_{N\pi}^2(y,k_\perp^2)$ is the invariant mass squared of the intermediate Fock state

$$M_{N\pi}^2(y,k_\perp^2) = \frac{m_N^2+k_\perp^2}{y} + \frac{m_\pi^2+k_\perp^2}{1-y}. \qquad (8)$$

We use an exponential form for the cutoff

$$G_\pi(y,k_\perp^2) = \exp(\frac{m_N^2 - M_{N\pi}^2(y,k_\perp^2)}{2\Lambda^2}) \qquad (9)$$

which insures that the identity (6) is satisfied [10,18]. We use Holtmann's parametrization [17] of the bare nucleon symmetric sea ($\bar{Q}_{\rm bare} = u_{\rm sea} = \bar{u}_{\rm sea} = d_{\rm sea} = \bar{d}_{\rm sea}$)

$$x\bar{Q}_{\rm bare}(x) = 0.11(1-x)^{15.8}. \qquad (10)$$

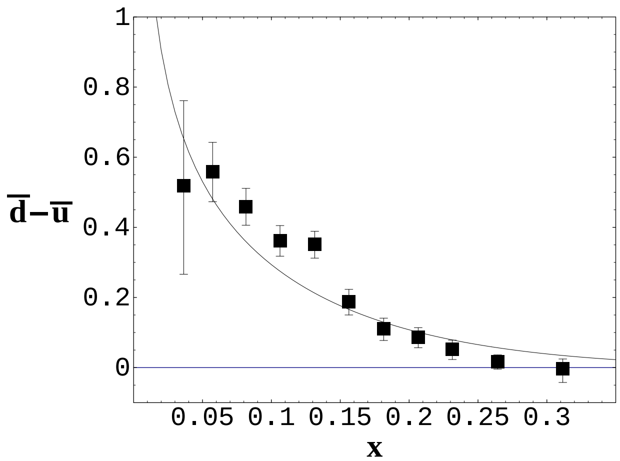

Figure 1. Comparison of our pion cloud model with data [3] for $\bar{d}(x) - \bar{u}(x)$. The cutoff constant $\Lambda = 0.83$ GeV, for which $D = \int_0^1 (\bar{d}(x) - \bar{u}(x))dx = 0.100$.

Since gluon splitting is the origin of this sea, we also use a harder distribution for the bare sea quarks, of the form found in a recent determination of the gluon distribution [19]

$$x\bar{Q}'_{\rm bare}(x) = 0.0124x^{-0.36}(1-x)^{3.8}. \tag{11}$$

For the pion valence quarks q_v and sea quarks $q_{\rm sea}$ we use [20]

$$xq_v(x) = 0.99x^{0.61}(1-x)^{1.02}, \qquad xq_{\rm sea}(x) = 0.2(1-x)^{5.0}. \tag{12}$$

The π-nucleon coupling constant is taken as $\frac{g_\pi^2}{4\pi} = 13.6$ The value of $\Lambda = 0.83$ GeV is chosen to reproduce the integrated asymmetry $D = 0.100$ [3].

3. Discussion

The results of our calculations for $\bar{d}(x) - \bar{u}(x)$ are shown in Fig. 1, and those for the ratio $\bar{d}(x)/\bar{u}(x)$ are shown in Fig. 2. In Fig. 1 the flavor asymmetry is caused entirely by the π^+, and our result is not affected by the different forms we have chosen for the bare sea FS contribution. In Fig. 2 the solid curve shown is for the perturbative sea quark distribution of (10). The dashed curve is for the gluonic form of (11). It is clear from Fig. 2 that a better description of the present data is provided by using a harder distribution for the symmetric sea. Of course other FS contributions could produce a similar improvement in agreement between theory and experiment. We have recently examined the role of the ω in the meson cloud of the proton and find this to be the case [21]. The σ meson would also tend to suppress $\bar{d}/\bar{u}$. A complete calculation must include all the components of the meson cloud.

Forthcoming analyses of new E866 data [22] and proposed experiments [23] will further test our models of both perturbative and non-perturbative contributions to the flavor-symmetric and flavor-asymmetric components of the proton sea.

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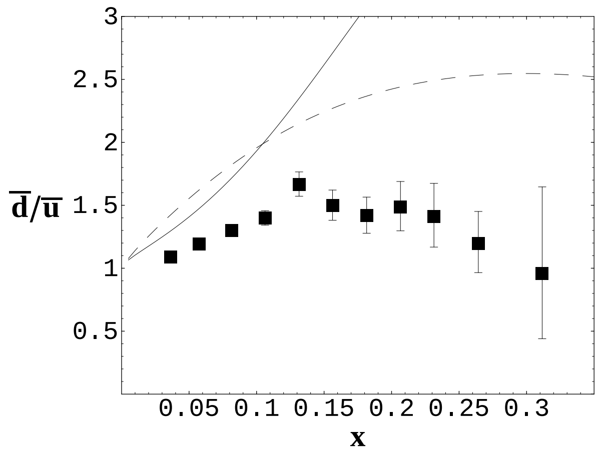

Figure 2. Comparison of our pion cloud model with data [3] for $\bar{d}(x)/\bar{u}(x)$. The solid curve is for the perturbative sea quark distribution of (10). The dashed curve is for the gluonic form of (11).

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